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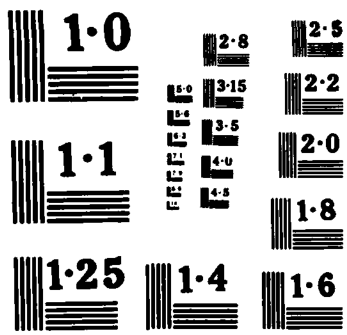

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DISPLAY AREA OF SINUSOIDAL GRATINGS AND
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BY

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DISPLAY AREA OF SINUSOIDAL GRATINGS AND LOW SPATIAL FREQUENCY CHANNELS

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ABSTRACT

The relation between stimulus size of sine gratings and low spatial frequency channels has been systematically investigated by television technique.

Experimental data suggest that the human visual system contains low spatial frequency channels. Variation of the stimulus area of gratings is a significant condition for the display of the low spatial frequency channels. It was found that as the area of sine gratings increases (from 1°, 2° to 5°, 10° field), human eyes become more sensitive to the low spatial frequency, to which the position of the lowest spatial frequency channels leads. The adaptable range of the low spatial frequency is extended (from 3 c/° to 0.2 c/°). For a 10° visual field, the position of the lowest spatial frequency channels stays at 0.3 c/°. The asymmetry of the bandwidth of the low spatial frequency channels has also been observed.

In the human visual system there is a spatial frequency channel system in which each channel is selectively sensitive to a limited range of spatial frequency. But C. Blakemore and F. W. Campbell (1969) [1] found, by studying the adaptation process, that when the vision angle was in the range of 1.5°, there was no threshold increase for any adaptation of spatial frequency less than 3 c/°. For lower adapting frequencies, less than 3 c/°, the peak of the after effect stayed at 3 c/°. Thus, it can be seen that there are no spatial frequency channels below 3 c/°. D. J. Tolhurst (1973) [2] indicated from his experiments of a

4.1° visual field, that the lowest adaptable channel would be extended to 1.5 c/° by expanding the visual angle. Moreover, the lowest adaptable channel was extended as low as 0.66 c/° when the gratings were made to move. In brief, whether or not there exists a low spatial frequency channel, what are the conditions and characteristics of its existence? This is not yet distinctly understood; a thorough study has to be made. The purpose of the experiments explained below is to describe systematically the effect of variation of sinusoidal grating area on channels at low spatial frequencies.

Method

In the experiments noted above, the sinusoidal gratings were generated by a television technique. A 9-inch black and white monitor (model Xin Huo 71-9) was modulated using the signals generated by a standard signal generator (XB18 or XD1) so as to make it generate vertical sinusoidal gratings on the screen. The spatial frequency and contrast of sinusoidal gratings can be changed by regulating the frequency and amplitude of the signals. A synchronous signal generator was assembled in order to hold the sinusoidal grating patterns strictly stationary. Thus, the sinusoidal signals at different frequencies were put into the monitor, passing first the synchronous signal generator; as a result, the gratings generated on the screen were very stable.

In order to prevent the effect of diffused light, the subjects viewed the target with an observation tube on which was applied a black coating. An artificial pupil was set up on the tube; the diameter of the pupil was 2.5mm. The object of observation was a circular grating. With the object fixed at 70 cm distance, the alterations of the grating area changed the size of visual angles which can be calculated with formulas. The variations of sinusoidal grating area used in the experiments were expressed as visual angles: 1°, 2°, 5°, 10°.

In the experiments, the space averaged mean luminance of the screen was 1 cm/m^2 using a color luminometer, BM2, made in Japan. The contrast of stimulus was defined as:

$$C = \frac{L_{max} - L_{min}}{L_{max} + L_{min}}$$

where C is contrast, L_{max} is the luminance of the peak of the sinusoidal grating and L_{min} the luminance of the trough.

A determination of the grating contrast using a luminometer UDT made in the USA indicated that the correlation between the modulated voltage and the contrast of the stimuli were linear. In the experiments, the mean luminance was unaffected by changes in the contrast and spatial frequency. In the experiments, the contrast sensitivity of the subjects towards the sinusoidal gratings of different spatial frequencies was determined first. The process specifically was: the subjects first adapted to the darkness for five minutes, then the contrast potentiometer was adjusted micrometrically. When the subjects set the sinusoidal grating of a spatial frequency so they could be detected, the tester recorded the amplitude of the voltage of input signals on a high frequency oscillometer (model SR8). This is the contrast threshold of the subjects (expressed by the voltage value) to certain spatial frequencies. Since the correlation between the modulated voltage and grating contrast was known, it could be transformed to the contrast threshold of the real sinusoidal grating. The final results were represented by the inverse of the contrast threshold, i.e., the contrast sensitivity. In the experiments, each spatial frequency was determined five times, and the average was taken as the real contrast threshold .

The procedure of the experiments for determining the adaptable after effect was as follows:

The tester detected first the contrast threshold of the subjects using the above mentioned method, then the subjects adapted

for three minutes to a high contrast (fixed at 0.5 in the experiments) spatial frequency (called adapting frequency). The subjects were instructed to not fix on any one spot of the gratings, and to allow his eyes to scan the gratings randomly; in this way, after images of the adapting grating were not generated. After the adaptation, the tester detected immediately the contrast threshold of the adjacent spatial frequency which was close to the adapting frequency. In the experiments the tester first detected, at random, the contrast threshold of the adjacent frequencies whether higher (called upper side frequency) or lower (called lower side frequency) than the adapting frequency. In the tests of different adjacent frequencies, the subjects were allowed to adapt for 20 seconds more to the adapting gratings of high contrast. The adapting frequencies used in the experiments were 3 c/°, 2 c/°, 1 c/°, 0.5 c/°, 0.2 c/°. The adjacent frequencies (upper side frequency and lower side frequency) were about two octaves. The computing method of the elevation of threshold before and after adapting is:

$$\text{relative threshold elevation} = \frac{\text{sensitivity before adapting}}{\text{sensitivity after adapting}} - 1$$

Three chosen subjects whose eyesight had been adjusted were experienced observers: two men and one woman. The subjects observed with their right eyes.

The experiment results were handled statistically.

Results of the experiments

1. The variation of the sinusoidal grating area and the contrast sensitivity

The most obvious effect of extending the grating stimulus was a marked increase in the contrast sensitivity to sinusoidal gratings of the low spatial frequency. Figure 1 shows that with the area increasing (from 1°, 2° to 5°, 10° field), the peak

of the contrast sensitivity moved to the low frequency. For example, the peak of the contrast sensitivity was 7 c/° when the visual angle was 1°, 6 c/° at 2°, 3 c/° at 5°. When the visual angle increased to 10°, the peak moved to 2 c/°. Moreover, when the area of grating stimulus was increased, low frequency cutoff occurred. But in comparison with the small visual angle, in the case of the big visual angle, the contrast sensitivity was biased evidently towards lower frequency. The figure shows that at 1° visual angle, low frequency cutoff happened at 1 c/°, and at 2° visual angle, the low frequency cutoff occurred at 0.7 c/°. But at 10° visual angle, the low frequency cutoff was prolonged to 0.15 c/°. These are the mean resultant curves of the three subjects. As for the curves of each individual subject, they are very similar to the mean resultant curves.

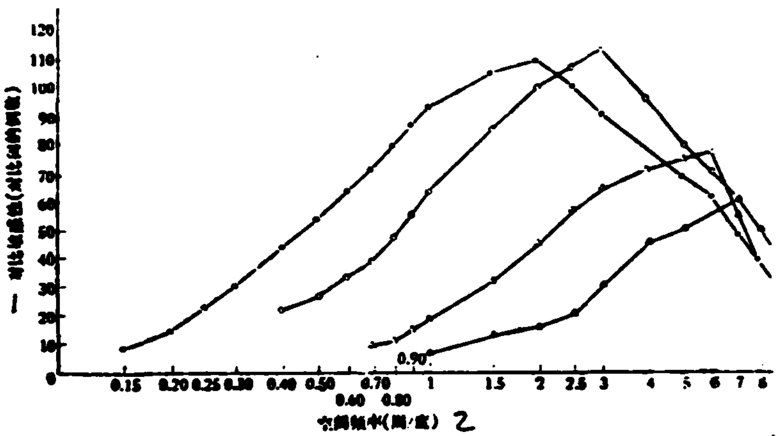

Figure 1. The influence of the change of the sinusoidal gratings area on the contrast sensitivity (the mean results of the three subjects).

Luminosity 1 cd/m^2, visual angles: ▲—1°, △—2°, ○—5°, ●—10°, the diameter of the right eye is 2.5 mm, observation with artificial pupil.

Key: 1--contrast sensitivity (inverse of the contrast threshold);
2--spatial frequency (c/deg)

2. <u>Influence of the variation of the sinusoidal gratings area on the low frequency channel:</u>

The influence of the variation of the sinusoidal gratings area on the curves of the grating adaptable curves is listed

in Table 1. Figure 2 is the typical grating adapting curves of the subject Mr. Yang. Table 1 shows that increasing the grating visualization area expanded the range of the low spatial adapting frequency of the human eyes. For example, when the visual angle is 1°, the adaptation to the spatial frequencies lower than 1 c/° has no evident threshold elevation, at 2° the spatial frequencies are below 0.5 c/°, and at 0°, there is no threshold elevation for the adapting frequencies below 0.2 c/°. In view of this, when the gratings area increases from 1° to 10°, the range of low spatial frequencies with threshold elevation can be expanded from 3 c/° to 0.2 c/°.

spatial frequencies (multiple frequencies)

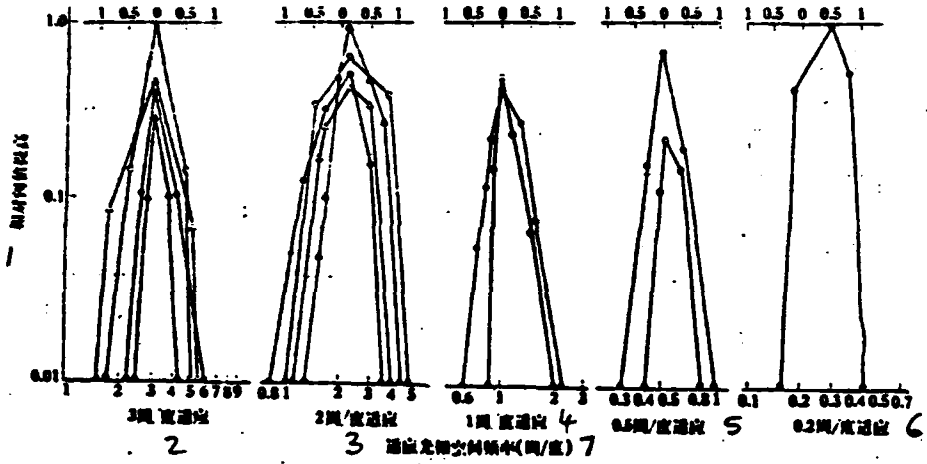

Figure 2. The influence of the variation of stimulus area of the sinusoidal gratings on the grating adapting after effect.

▲ -1° visual angle, Δ -2° visual angle, 0 -5° visual angle, ● -10° visual angle .

mean luminosity: 1 cd/m^2, adapting grating contrast: 0.5.

Key: 1--the elevation of the relative threshold; 2--adaptation at 3 c/deg; 3--adaptation at 2 c/deg; 4--adaptation at 1 c/deg; 5--adaption at 0.5 c/deg; 6--adaptation at 0.2 c/deg; 7-- variation of the stimulus area

In analyzing the peaks of the adapting curves (Figure 2), it is found that the peaks of the adaptable after effect for the gratings at 3 c/°, lc/°, 0.5c/° stay at the adapting frequencies, except the 2 c/° grating of which the peak of the grating adaptable curve is located at 2.25 c/°, and the peak /210

of the 0.2 c/° grating adapting curve is located at 0.3 c/°. The peak of the adapting curve represents the position of this adaptable spatial frequency channel. It can be seen from the above result that the positions of the lowest spatial frequency channel are changeable for the different grating visualization areas. For example, at 2.25 c/° for 1°, 2° at 0.5 c/° for 5°, and at 0.3 c/° for 10°. Therefore, when the grating visualization area increases to 10°, the position of the lowest adapting spatial frquency channel is at 0.3 c/°.

From above Figure 2 and Table 1, further analysis of the bandwidth property of the spatial frequency channel in the adaptation curves demonstrated that the curve of the 3 c/° grating adaptation had very fine symmetry. In other words, the upper side and lower side frequencies on both sides of the adaptable frequency are symmetrical. But the spatial frequency adapting curves below 3 c/° showed distinct asymmetry. Normally, the bandwidth of the upper side frequency is bigger than that of the lower side frequency. Furthermore, it seems that for the same adapting frequency at different visual angles, the bandwidth of the large visual angles (5°, 10°) is bigger than that of the small visual angles (1°, 2°). The bandwidths of the upper and lower side frequencies seen in the experiments are about ±0.80-1.24 octaves.

Discussion

Since the experiment conditions were limited (1.5° visual angle) in C. Blakemore and F. Campbell's work, they indicated that there was no spatial frequency channel below 3 c/°, because the position of the lowest adaptable spatial frequency channels was at 3 c/°. It is worthwhile to discuss this explanation again. In fact, using 4.1° visual angle, D. Tolhurst already found that the position of the lowest spatial frequency channel can be prolonged until 1.5 c/°. Our experiment results demonstrated, in a systematic way, that the positions of the lowest adapting spatial frequency channel change with the size;

at 10° visual angle, the position of the lowest spatial frequency channel is at 0.3 c/°.

From the experiment results, it is notable that low spatial frequency channels do exist. As the conditions for the visualization of the low frequency channel, besides the modulation in time of the gratings (movement of the gratings), the variation of the area of the visualization of gratings is also an important element.

The results of the experiments found also the asymmetry feature of the bandwidths of the low frequency channels (the frequencies at two sides of the adaptable frequency). At the adaptation of the spatial frequencies of 3-14 c/° (C. Blakemore and F. Campbell), the upper and lower side frequencies of the adapting frequency are symmetric.

The phenomenon of increasing the sensitivity to the low spatial frequency channels by expanding the visualization area can be considered as the periphery beyond the fovea of the retina attended the distinguishing of the spatial frequencies. Just as /233
viewed by C. Sharpe and D. Tolhurst, although the periphery is not sensitive to the high spatial frequency channels, it is more sensitive to the low spatial frequency.

Conclusion

1. The low spatial frequency channels exist. The variation of the grating visualization area is an important condition for displaying the low frequency channels.

2. With the increase of the displaying area of sinusoidal gratings (from 1°, 2° to 5°, 10°), the sensitivity of the human eyes to the low frequency gratings is raised, and the adapting range to the low spatial frequency is increased (from 3 c/° to 0.2 c/°).

Table 1. The effects of the variation of the stimulus area of the sinusoidal gratings on the aftereffects of the different spatial frequency adaptation (average of the three subjects)

1 适应频率 (周/度)	视角大小 (度) 2	3 邻近频率的带宽(倍频)			上下边频的对称性 7	最大适应后效的峰值(周/度) 8	备注 9
		上边频* 4	下边频** 5	带宽 6			
3	1°	0.75	0.88	1.63	10 不对称	3	
	2°	0.85	0.85	1.70	11 对称	3	
	5°	1.0	1.0	2.0	11 对称	3	
	10°	0.86	0.78	1.64	10 不对称	3	
2	1°	1.02	0.77	1.79	不对称	2.25	
	2°	0.93	0.68	1.61	不对称	2.25	
	5°	1.15	1.15	2.30	对称	2.25	
	10°	1.12	0.87	1.99	不对称	2.25	
1	1°						无适应后效
	2°	1.07	0.58	1.65	不对称	1.0	
	5°	1.55	0.53	2.08	不对称	1.0	
	10°	1.37	1.11	2.48	不对称	1.0	
0.5	1°						无适应后效
	2°						无适应后效
	5°	0.83	0.75	1.58	不对称	0.7	
	10°	1.10	1.10	2.20	对称	0.5	
0.2	10°	1.25	0.60	1.85	不对称	0.3	

* upper side frequency: frequency higher than the adapting frequency;

** lower side frequency: frequency lower than the adapting frequency.

Key: 1--adapting frequency (c/deg); 2--size of the visual angles (degree); 3--bandwidth of the adjacent frequency (octave); 4--upper side frequency; 5--lower side frequency; 6--bandwidth; 7--symmetry of the upper and lower side frequencies; 8--peak of the maximum adapting aftereffect (c/deg); 9--note; 10--asymmetry; 11--symmetry

3. The position of the lowest spatial frequency channel is prolonged to the low frequency by increasing the display area of gratings. At 10° visual angle, the position of the lowest adapting spatial frequency channel is at 0.3 c/°.

4. The bandwidth of the low frequency channels has the feature of asymmetry. Normally, the bandwidth of the upper side frequency is bigger than that of the lower frequency.

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adjustment of the instruments used in these experiments.

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